Estimation of energy substitution effect in China's machinery industry–based on the corrected formula for elasticity of substitution

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ABSTRACT

Characterized with high-energy consumption, China's machinery industry has seen a surge in its energy consumption reaching 540.743 Mtce (million tons of coal equivalent) in 2014, which is about 12.7% of China's total energy consumption. We try to examine inter-factor substitution towards energy conservation in the Chinese machinery industry by applying the corrected formula. Documented results evidence a significant substitution relation between energy and capital as well as labor. The estimated substitution elasticity between capital and energy is about 1.029 while that of labor and energy stands at 1.030. This is a clear indication that, allocating more capital or labor to China's machinery industry instead of energy will be vital in the CO_2 mitigation effort. Also, a practical scenario estimation to access energy conservation and CO_2 abatement indicates that, a 5% and 10% increase in capital inputs will reduce energy consumption by 27.742 and 55.483 Mtce while CO_2 emissions will reduce by 64.553 and 129.105 Mt respectively in 2014.

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1. Introduction

Machinery industry, which provides equipment for the various sectors of the national economy, is an important and basic part of manufacturing. According to *China Machinery Industry Yearbook* [1], machinery industry mainly consists of seven sub-sectors which include "manufacture of non-metallic mineral products, manufacture of metal products, manufacture of general purpose machinery, manufacture of special purpose machinery, manufacture of transport equipment, manufacture of electrical machinery and equipment, manufacture of measuring instruments and machinery for cultural activity and office work". Machinery production can play a crucial role in economic development and energy consumption in the process of industrialization and urbanization. High-energy input, heavy pollution and low efficiency are the main features of the machinery industry.

In the 21st century, the output (value added) of China's

machinery industry grew from 130.888 billion CNY (Chinese Yuan) in 2000 to 490.935 billion CNY in 2014 (with 1990 as the base period) [1]. Energy consumption in this sector also rose from 149.693 Mtce (million tons of coal equivalent) in 2000 to 540.743 Mtce in 2014 [2] (see Fig. 1). China has been actively promoting energy conservation and easing the bottleneck constraints of resources and environment, which is one of the keys to ensure the sustainable development of machinery industry.

Energy input in China's machinery industry has dramatically been increasing since the introduction of market economy and the implementation of reforming and opening up policy. China is the largest producer, consumer and importer of coal in the world, but has been plagued with environmental pollution caused by fossil energy consumption. China has been a net oil importer since 1993, and its dependence on foreign oil reached about 50% in 2005 [3]. In 2010, China surpasses the US for the first time to become global largest energy consumer [3]. Meanwhile, natural environment in China continues to worsen with economic development and continuous increase in CO_2 emissions, posing a serious threat to the world. In 2011, the US Embassy in China broadcast PM2.5, which finally sparked widespread concern in Chinese society. According to the UN Environment Report, at the end of 2012 the proportion of cities which met ambient air quality standards was less than 25%,

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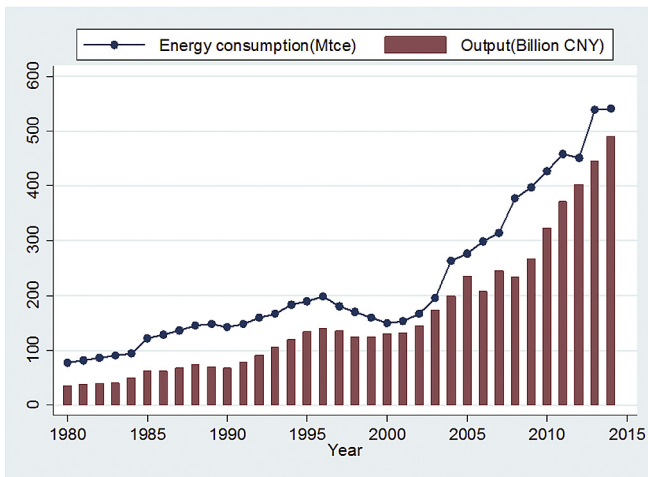
The output and energy consumption in China's machinery industry during 1980–2014.

and about 30% of the major rivers and 60% of groundwater had been contaminated in China [4].

On Dec 12th, 2015, almost 200 Parties of United Nations Framework Convention about Climate Change unanimously consented to sign the Paris agreement. The Paris agreement is strictly to control the temperature rise within 2 °C, and to chase the target of 1.5 °C [5]. If the target is less than 2 °C, global greenhouse gas emissions in 2030 should be controlled at 40 billion tons or less [6]. In 2013, CO_2 emissions from China account for about a quarter of the global total. the proportion of China's CO_2 emissions is about 29% in the global [7]. If this ratio is unchanged, China needs significantly to reduce CO_2 emissions over the next ten years.

In view of the importance of environmental issues in China, high energy-consuming machinery industry is expected to make a due contribution to energy conservation and CO_2 abatement. In 2014, energy consumption in China's machinery industry was about 540.743 Mtce, which accounts for about 12.7% of China's total energy consumption [2]. With the gradual advancement of industrialization and urbanization, energy consumption in China's machinery industry may still maintain at a high level in the next ten years or more. Due to the use of too much fossil fuel, energy conservation has become a very important issue. There are some approaches which may save energy such as improving energy efficiency, raising energy prices, adjusting carbon/energy tax and so on. In this article, we tried to solve this problem by using more capital or labor, but less energy. Therefore, exploring energy substitution in the machinery industry has important significance for China's current energy conservation. Some scholars have used flawed formula to calculate the substitution elasticities between all pairs of input factors. For instance, Smyth et al. [8] studied energy substitution effect on China's iron and steel industry. In that paper, the formula for elasticity of substitution given was incorrect. We correct the existing formula by giving a detailed derivation. Then according to the corrected formula, we explore energy substitutability in the Chinese machinery industry.

Since energy is one of the factors of production, energy and non-energy inputs are put into production in accordance with a certain proportion and may substitute for one another to some extent. Under the premise of the substitutability, it is possible to achieve the dual goals of economic growth and energy conservation by changing the combination of energy and non-energy input factors. Thus, there are two points that need to investigate in the machinery industry production. Firstly, to what extent can other input factors

substitute for energy? Secondly, what impact does the substitution result have on the machinery industry's development and energy conservation?

In the background of sustainable economic development and increasing environmental pollution, China's machinery industry faces with constraints of energy consumption. It has become a critical point on how to optimize the allocation of resources, improve energy efficiency and reduce energy intensity in the machinery industry's development. In this paper, we try to study substitution effect between energy and capital as well as labor in China's machinery industry during the period 1980–2014.

The remaining part of this article is organized as follows. The second part outlines the development of global machinery industry. The third part consists of literature review about energy substitution. In the fourth part, we describe the translog function model and derive the formula for elasticity of substitution. The fifth part is the data source and processing. The sixth part is the empirical results and scenario analysis. The seventh part is the conclusion and policy suggestions.

2. An outline of the development of global machinery industry

Machinery industry has been famous and considered as the industrial heart of production and the basis for the development of economic sectors. Its level of development is an important indicator for measuring the degree of industrialization. Global economic growth is inseparable from the continuous progress of machinery industry, and vice versa. The machinery industry, whose global output value reached $1.85 trillion in 2007 [9], is an important driver of the economy and an important part of the manufacturing worldwide. The development of global machinery industry has three major trends, which might have a profound impact on the global energy, economy and environment. These trends are as follows. Firstly, the focus of the entire machinery industry will move to Asia. Secondly, the competition in the world's market will cluster in mid-market and energy conservation. Thirdly, environmental protection will draw more and more attention from users and manufacturers. Following the global manufacturing's gradual movement to Asia in order to obtain localized cost advantages and more local customers. Asia's machinery industry is rapidly growing and its share in the world market has expanded year by year.

In the early 21st century, the world's largest machinery enterprises are almost located in the United States, Japan, and Europe. The US, Germany and Japan have almost been the largest producers and suppliers of machinery products. In recent years, some Asian countries such as China, South Korea and so on play a more and more important role in the production and export of machinery products worldwide. Due to sustained economic development, consumption of machinery products has also increased substantially in Asian countries. Machinery manufacturing base transferred from developed countries to developing ones, which provided uncommon opportunities of production and export for the latter like China, South Korea, India, etc. South Korea and China respectively shared 4% and 7% in global total production of machinery. India's share was still insignificant 1.4%, which showed ample range for enlarging in its market share [10].

In the case of China, especially after joining the WTO (World Trade Organization), the Chinese government has vigorously been promoting high-speed rail, engineering machinery, automobile, steel, cement and other equipment to the world, which will drive the development of many enterprises producing mechanical spare parts. As optimistic about China's market prospects, multinational companies have successively entered China, which will help to expand the production capacity of machinery industry, improve the